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EFFECTS OF MANUFACTURING AND DEPLOYMENT ON THIN FILMS FOR THE NGST SUNSHADE

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Abstract

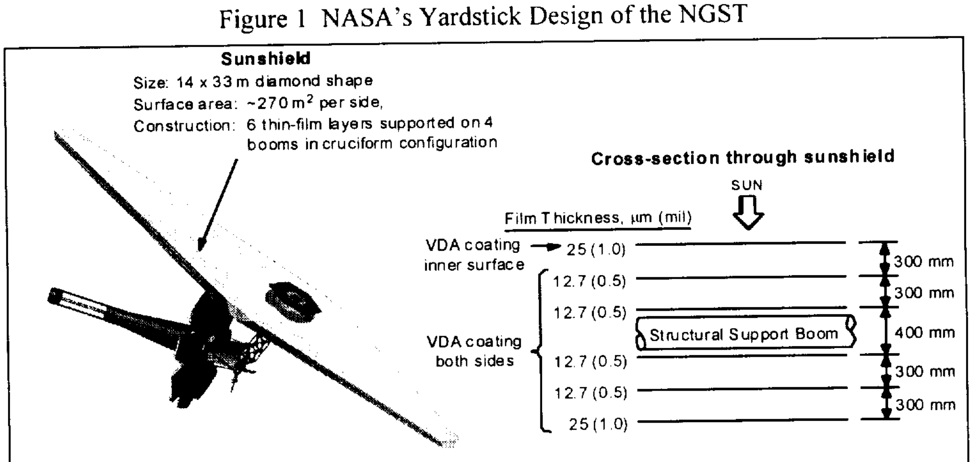
The Next Generation Space Telescope (NGST) is being developed as an advanced astronomical observatory. The NGST proposes to utilize several thin film membrane layers to create a shield for protection of the telescope from solar thermal energy and stray light. The shield will take the form of a polygon, approximately 15 x 30m, with individual membrane layers positioned so that they do not come in contact with one another. The membrane shield will be deployed and supported by a series of booms, which will be packed into a small volume for launch. Finally, the shield will be deployed on orbit. Several film materials are being considered for the membrane shield, including CP1, Kapton E, Kapton HN, and Upilex. Each of these polyimide materials was tested to determine their durability over the 10-year mission. New facets of materials testing have been introduced in this study to develop performance data with greater realism to actual use, particularly that of degradation from packing, launch and deployment processing. Materials were exposed to handling that simulated the life of the materials from manufacture through deployment with standardized fixtures and then exposed to a simulated, L2, 10-year radiation environment. Mechanical and thermal radiative properties were measured before and after each phase of testing. This paper summarizes the program and test results.

Introduction/Background

The optics and detectors for NGST are expected to operate at IR wavelengths between 0.6 and 30μm. To accomplish this goal, the optical telescope assembly (OTA) and the integrated science instrument module (ISIM) will have to operate at temperatures below 50 K. To achieve cryogenic temperatures, several of the current designs for NGST use a large, deployable sunshield to passively cool the telescope. These concepts for the sunshield consist of 4 to 8 layers of thin film thermal control material (12.5 to 25 microns thick) supported by deployable struts. The sunshield will have to survive for 10 years in a deep space environment.[1]

The current NASA yardstick concept is a 6-layer, diamond-shaped sunshield that is 33 m long by 14 m wide, with a surface area of 270 m^2 (see Figure 1). The layers are spaced 0.3 to 0.4 meters apart. The outermost layers will be 25 μm thick and the inner layers will be 12.5 μm thick. All surfaces have a vapor deposited aluminum (VDA) coating except for the sun-facing surface. The sun-facing surface may have an optical coating to improve the thermal performance of the sunshield. The layers of the sunshield are currently base lined to be fabricated from Kapton HN polyimide film.

Figure 1 NASA's Yardstick Design of the NGST



American Institute of Aeronautics and Astronautics

Sunshield thermal performance, critical to the OTA and ISIM designs, hinges on well characterized sunshield materials, accurate analysis, and thorough testing. The need for good characterization was dramatically highlighted by the discovery of a 3 foot crack in the Teflon film used on Hubble Space Telescope (HST) during its second servicing mission. The astronauts observed severe cracking in the outer Teflon layer on *both* solar and anti-solar facing Multilayer Insulation (MLI) Failure Review Board (FRB) found that high-energy electrons, protons, UV ultimate strength and elongation of the Teflon was significantly reduced. Testing done by the HST surfaces (see Figure 2). Analysis of a sample brought back from the servicing mission found that the high energy electrons, protons, UV and x-ray radiation and thermal cycling caused the embrittlement and cracking found in the HST thermal blanket.[2]

As a result of these findings, it became clear that the films must be fully tested and characterized before choosing one for the NGST sunshield so that the same thing that happened to HST does not occur on NGST: on NGST there will be no opportunity to do a repair. If the sunshield is lost, the mission is lost.

In spring 1999, a study was formulated to evaluate candidate thin film polymers for the sun-facing layer of the NGST sunshield. The candidate thin films identified at that time were CP1, CP2, Kapton E,

Figure 2 Astronauts Tanner and Harbaugh translate the HST Light Shield during the second repair mission (17 Feb 97), after discovering a 3 foot crack in the MLI.

Kapton HN, TOR-LM and Upilex-S. Except for the TOR-LM, which is polyarylene ether benzimidazole (PAEBI), these films are polyimides. CP1 and CP2 are trademarks of NASA Langley Research Center (LaRC) and are produced by SRS Technologies. Kapton E and Kapton HN are trademarks of Dupont. TOR-LM is also a trademark of LaRC and is produced by Triton Systems Inc. Upilex-S is a trademark of UBE Industries, LTD.

Previous studies on the durability of films in various radiation environments have been performed. [3, 4, 5] This study focuses on NGST membrane application of films that have been handled and will be flown at L2 for 10 years.

NGST Sunshield Requirements

The primary requirement of the NGST sunshield is to shade the OTA and ISIM from the sun, to allow them to passively cool below 50 K. To achieve this requirement, the sunshield must shade an area of about 275 square meters to block the sun from the telescope. Due to the size of the sunshield and the size restrictions of available launch vehicles, the sunshield will have to be stowed and then deployed once the spacecraft is released. The thin film layers of the sunshield must be durable enough to withstand ground handling, stowage and deployment.

Over the last 3 years, the thermal requirements for the sunshield became more stringent due to stray light requirements. To help meet the current thermal requirements for NGST, it is desirable that the ratio of solar absorptance (α) over IR emittance (ε) for the sun-facing layer be less than 0.4 at end of life (EOL).[6] The current baseline sun-facing layer for the NASA sunshield concept (Kapton HN with VDA on the backside) has a beginning of life (BOL) α/ε ratio of 0.6.

In addition to meeting the thermal requirements for NGST, the sunshield must also survive a demanding environment of mechanical stress, radiation exposure and micrometeoroid impacts. With regard to mechanical stress, the sunshield must be stowed in a relatively small volume, resulting in each of the sunshield layers receiving many folds (see Figure 3). Once deployed, the layers will have to be tensioned to flatten them and to prevent them from touching each other (see Figure 4). The layers of the sunshield will only be supported at a few points, so there may be zones of high stress concentration as well. Since the sunshield layers will have to be folded and deployed, there is a chance that the material may tear.

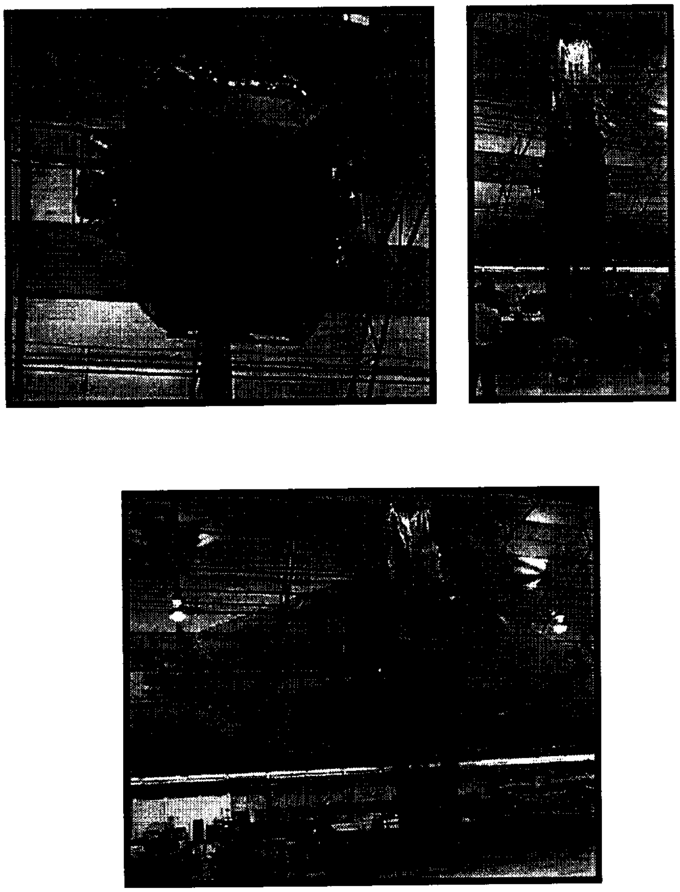


Figure 3 – Stowed Shield, Lateral Deployment, and Longitudinal Deployment

Since a tear can easily propagate in materials like Kapton and most other polymer films 25 μm or less, some type of rip-stop may be necessary. The layers of the sunshield will need to have good impact resistance, folding endurance and tear strength to meet the NGST sunshield requirements. Any coatings that are used on the layers (VDA internally and any used on the sun-facing layer) will have to remain adhered as well.

The primary constituents of the NGST orbital radiation environment at L2 of concern for the sun-facing layer of the sunshield are solar wind and solar ultraviolet (UV) radiation. The solar wind is composed of electrons, protons and heavier ions (mostly hydrogen). These particles have an average velocity of 400 km/s and an energy of 10 to 50 eV. The solar wind and UV will degrade the thermal and mechanical properties of thin film polymers with prolonged exposure.

The micrometeoroid environment at L2 is not well understood, but the sunshield layers are expected to have to withstand impacts from particles with a mass of 10^{-8} to 10^{-2} grams traveling at an average velocity of 17 km/s. The micrometeoroid environment may be a driver in the design of the sunshield as the effect of impacting particles is partially controlled by the thickness and spacing of the film layers. Some of the film layers may have to be reinforced to reduce micrometeoroid damage, adding mass to the sunshield and making stowage more difficult.

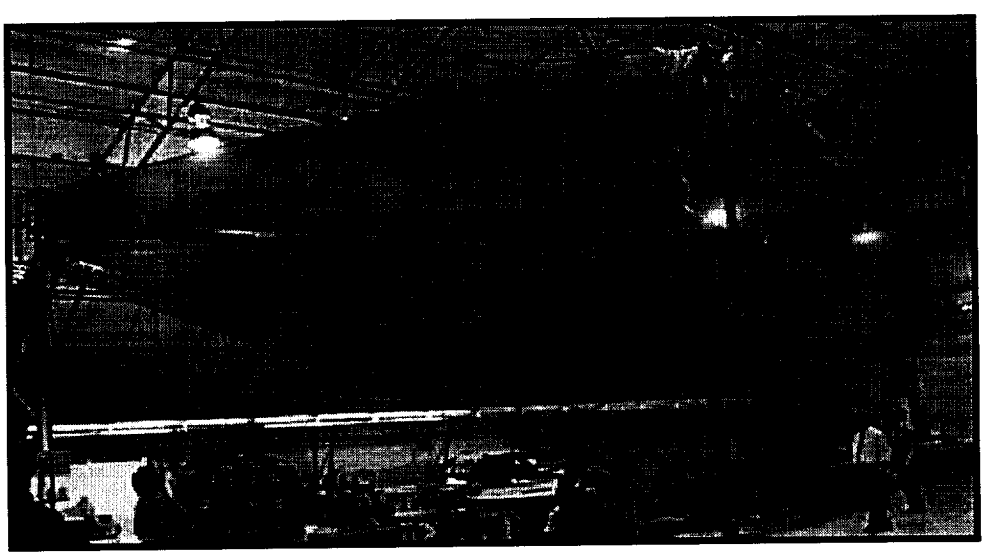


Figure 4 – The Fully Deployed Sunshield

Candidate Materials

The candidate materials selected for this study originally included CP1, CP2, Kapton E, Kapton HN, TOR-LM and Upilex-S. CP2 and TOR-LM are not selected for this phase because of their performance in an earlier phase of this study. Both materials become brittle after exposure to a simulated L2 radiation environment, and in some cases the degradation is severe enough to prevent mechanical testing.

The candidate materials selected for this phase of the study were CP1, Kapton E, Kapton HN and Upilex-S, as described in Table 1. Samples of Kapton HN with a Ag/Al_2O_3 coating on the sun-facing side were included since previous work found that none of the materials with only VDA on the back side would meet the EOL requirement of an α/ε ratio less than 0.4. The BOL α/ε ratio of the coated Kapton HN is around 0.2. CP1 has a lower tensile strength and elongation at failure than the other three materials. Kapton E, Kapton HN and Upilex-S have a lower coefficient of expansion (CTE) than CP1, which is desirable in designing a multi-layer sunshield where each layer will be at a different operating temperatures. Even though CP1 does not have the higher strength and lower CTE of the other materials, it is included in this study because it is not clear what the effects of handling would be on this material.

Test Plan

The purpose of this phase of the study is to evaluate the combined effects of ground handling, folding, stowage, deployment and exposure to the radiation environment at L2 on selected films. A 10-year equivalent L2 solar wind electrons/protons and 1000 equivalent sun hours (ESH) of UV (200 to 400 nm) exposure of manipulated 25 μm samples was performed at Boeing in Seattle, Washington. The samples were manipulated at ILC Dover in Frederica, Delaware prior to exposure.

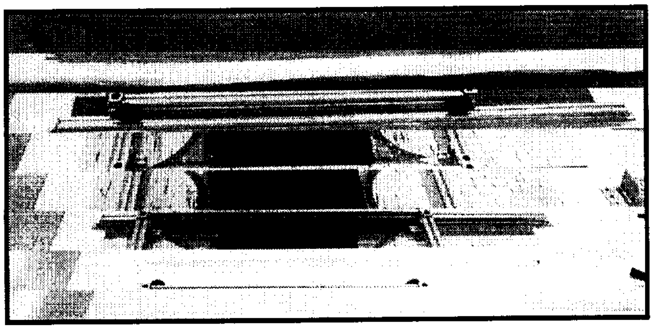
Table 1 – Thin Film Material Candidates Tested

Material Description	**Material Designator**	**Coating**	**Coating Thickness (Å)**
Kapton E	KE	VDA	1100 ~ 1200
Kapton HN	KHN	VDA	1100 ~ 1200
Coated Kapton HN	CK	Ag/Al_2O_3-(VDA)	15000-(1000 VDA)
Upilex	U	VDA	1000
CP1	CP	VDA	1400

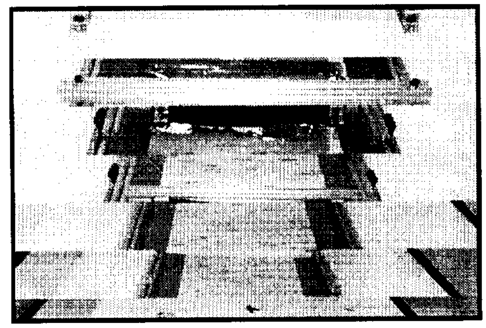
Manufacturing and Deployment Simulations

The large sunshades in several NGST concepts consist of multiple layers of coated thin polymer membranes under tension. In the actual application, these membranes could experience operational temperatures from –184°C [89 K] to 127°C [400 K]. The current materials under consideration for these membranes have been characterized in the past, but very little is known about their degradation due to process handling and performance at extreme operational temperatures. The purpose of these tests is to characterize the performance of the selected thin film materials which have been processed through handling that simulated the life of the assembly and tested at NGST operational temperatures. Capturing the effects of handling packing and deployment processes is important because during the fabrication and assembly processes, and subsequently during launch and deployment, they will experience scuffing and wrinkling that could significantly degrade the film/coating.

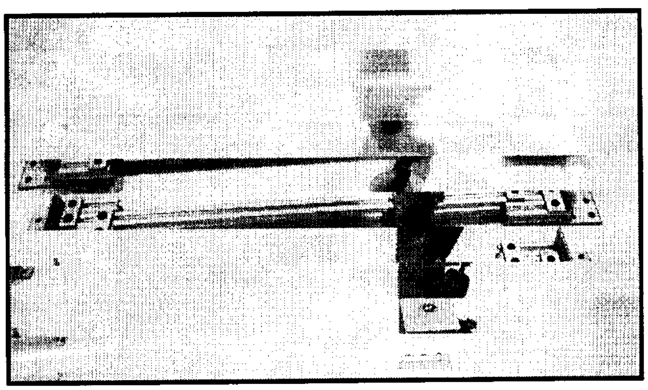
Prior to the mechanical properties tests, material samples were exercised through four handling simulation fixtures (see Figure 5). The four handling simulations represented conditions that will be experienced from film manufacture, through fabrication of the sunshield assembly, to deployment in space. Simulating this process is imperative because during the fabrication process, the membrane material will experience sliding and bunching (thus, potential surface scuffing and wrinkling), and during the assembly process, seaming (thus, potential membrane damage caused by the assembly tools). Furthermore, after fabrication and assembly the membrane system will go through several packing and deployment trials before the final deployment in space.



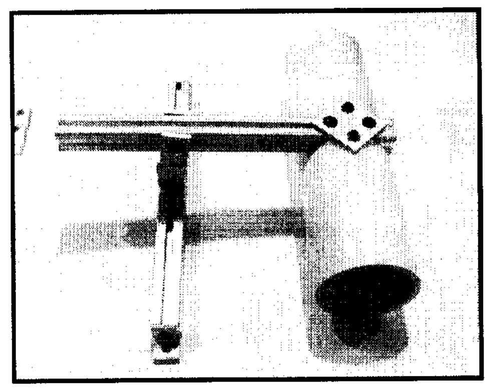
Scuffing Simulation Fixture



Wrinkling Simulation Fixture



Assembly Simulation Fixture



Packing and Deployment Simulation Fixture

Figure 5 – Handling Simulation Process: During the fabrication process the membrane material will experience handling in the form of sliding and bunching (thus, scuffing and wrinkling), and assembly processing in the form of seaming (thus, potential damage caused by the roller).

Mechanical Tests

Several mechanical properties tests were conducted on materials in their pristine condition, after handling tests, and after exposure to simulated space environment. The mechanical tests were performed at three different temperatures in order to test at the temperatures expected for NGST operation and to build correlation of data. The mechanical tests performed were Tensile Properties Test, Tear Resistance Test, and Flex Test.

Tensile Properties Test

The tensile properties test performed in this effort is an extension of the ASTM D 882-97 Standard Test Method for Tensile Properties of Thin Plastic Sheeting. Additional steps were added to capture the effect of handling due to manufacturing, packing and deployment, and the extreme conditions of space that would be experienced by the NGST Sunshade material. The objective of this test is to determine the tensile properties (particularly the tensile strength), the percent elongation at break, and the modulus of elasticity of a given material sample in pristine, handled and post environmentally exposed conditions. The tensile properties tests were performed at three temperatures: laboratory ambient, maximum operational temperature of 127°C [400 K], and minimum operational temperature of -184°C [89 K].

This experiment consisted of the five candidate NGST Sunshade material samples (see Table 1) with the same nominal thickness of 25.4 μm. Prior to the tensile properties test, material samples earmarked for handling (or manipulation) were exercised through the four handling simulation fixtures pictured in Figure 5. The handling simulations were conducted in sequence beginning with the surface scuffing simulation, followed by the wrinkling simulation, the roller simulation, and finally packing and deployment simulation. After handling simulation, both pristine and handled materials earmarked for irradiation exposure were sent to Boeing and arranged in the test fixture for controlled exposure.

Observations:

Comparing the tensile strengths of the specimens (See Table 2), from pristine (pre-handling) ambient condition to manipulated (post-handling) maximum operating temperature, and to irradiated-manipulated samples, the following trends are observed. First, for all materials tested, when comparing manipulated specimens under maximum operational temperature (identified with the extension C-M-H) with pristine specimens under ambient condition (identified with the extension C-P-A), tensile strength decreased significantly. Likewise, the significant decrease in tensile strength is also observed for all materials tested when comparing irradiated-manipulated specimens (E-M-A) with the pristine specimens. From the increase of apparent modulus and significant decrease in both tensile stress and apparent failure strain after exposure to radiation, it is clear that these classes of materials harden or become brittle when exposed to radiation and therefore suffered strength degradation.

Second, when comparing the results of tensile strength tests in all seven test cases, most of the film samples are primarily influenced (i.e. strength decreased) by the extreme operating temperature, with the exception of CP1 where the specimens did not survive irradiation. In other words, aside from CP1, the change of material properties for this class of materials is most affected by temperature changes. The significance of this temperature sensitivity is that the outer most layers, both facing the sun and deep space, must be designed with this factor taken into consideration.

Third, in terms of the tensile strength degradation trend, all three conditions: environmental exposure, handling simulation, and high temperature contributed to strength degradation. For example, Kapton E exhibited a tensile strength decrease on average of 6.6 percent from just handling simulation alone, 20.00 percent from maximum operating temperature alone, but 29.41 percent in the combined case with handling and high temperature. Furthermore, Kapton E exhibited a tensile strength degradation of less than 1.0 percent from just irradiation alone, but 21.14 percent in the combined case with handling and irradiation exposure. Radiation exposure did not reduce tensile strength significantly for Kapton E. However, the exposed material became brittle evidenced by the increase of apparent modulus and decrease of apparent failure strain.

Fourth, Upilex exhibited the highest tensile strength for all seven test cases, and CP1 the lowest in the same seven cases. Tensile test at ambient temperature was not performed for pristine CP1 exposed to irradiation because 3 out of 4 CP1 specimens did not survive the irradiation exposure.

Finally, in the actual application, these materials might experience high membrane stress in conjunction with extreme temperatures. Under this condition of combined stress and temperature the performance of some of the materials tested might be marginal. Therefore, implementation of innovative designs that reduce membrane stress and temperature is critical when structurally marginal materials must be used.

Tear Resistance Test

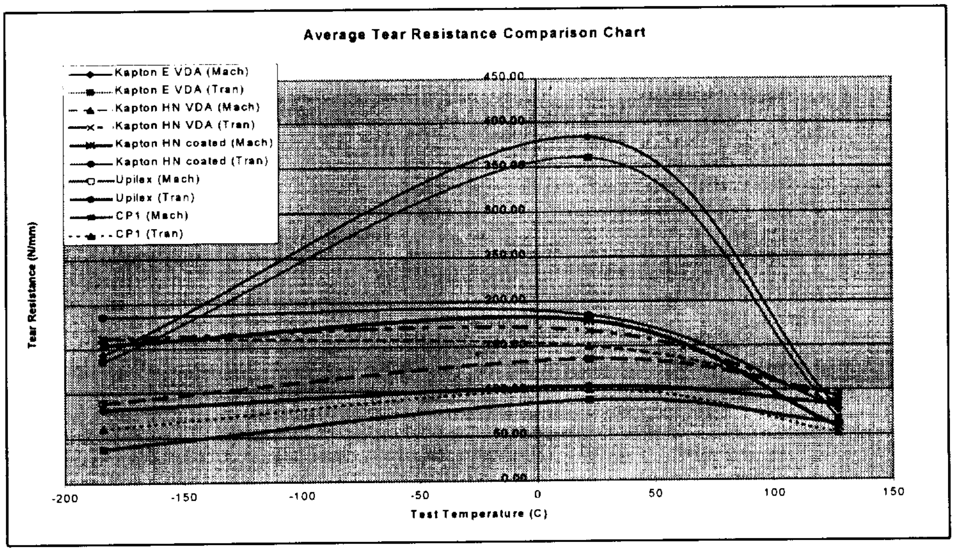
The tear resistance test performed in this effort is an extension of the ASTM D1044-94a, Standard Test Method for Initial Tear Resistance of Plastic Film and Sheeting. Additional steps were added to include the extreme conditions of space that will be experienced by the NGST Sunshade material. The objectives of the thin film tear resistance test are: (1) To determine the force that would initiate tear in a given material sample under conditions of laboratory ambient, maximum operational temperature of 127°C [400 K], and minimum operational temperature of −184°C [89 K]. (2) To determine changes in tear strength at the extreme temperatures. (3) To obtain a relative ranking of the tear resistance of various material samples tested under similar conditions and comparable thickness (Figure 6).

In this set of tests, the five candidate materials (see Table 1) with the same nominal thickness 25.4 μm (0.001 in.) are tested in three different environmental conditions. The three conditions represent the ambient laboratory condition and the predicted extreme temperatures of the NGST Sunshade. Each test consisted of ten (10) specimens in both machine and transverse directions.

Table 2 – Tensile Properties

Material Description	Sample ID	Sample Description	Apparent Modulus		Ult. Tensile Stress		Apparent Failure Strain (%)
			ksi	Mpa	ksi	Mpa	
Kapton E	KE-C-P-L	Control/Pristine/Low	973.331	6710.88	59.117	407.60	25.4
	KE-C-P-A	Control/Pristine/Ambient	698.440	4815.57	39.160	270.00	43.6
	KE-C-P-H	Control/Pristine/High	512.549	3533.90	31.330	216.01	49.9
	KE-C-M-A	Control/Manipulated/Ambient	667.810	4604.38	36.552	252.02	44.2
	KE-C-M-H	Control/Manipulated/High	431.348	2974.04	27.641	190.58	54.2
	KE-E-P-A	Exposed/Pristine/Ambient	878.856	6059.49	39.082	269.46	33.9
	KE-E-M-A	Exposed/Manipulated/Ambient	1005.148	6930.24	30.903	213.07	10.3
Kapton HN	KHN-C-P-L	Control/Pristine/Low	619.057	4268.24	45.321	312.48	35.2
	KHN-C-P-A	Control/Pristine/Ambient	408.164	2814.19	28.302	195.14	59.4
	KHN-C-P-H	Control/Pristine/High	287.631	1983.15	21.459	147.95	63.4
	KHN-C-M-A	Control/Manipulated/Ambient	340.268	2346.06	27.657	190.69	62.2
	KHN-C-M-H	Control/Manipulated/High	268.646	1852.25	20.975	144.62	67.9
	KHN-E-P-A	Exposed/Pristine/Ambient	461.119	3179.30	27.590	190.23	32.6
	KHN-E-M-A	Exposed/Manipulated/Ambient	526.899	3632.84	25.936	178.82	28.1
Coated Kapton	CK-C-P-L	Control/Pristine/Low	834.908	5756.49	43.709	301.37	29.0
	CK-C-P-A	Control/Pristine/Ambient	419.347	2891.30	26.128	180.15	64.5
	CK-C-P-H	Control/Pristine/High	274.940	1895.65	19.927	137.39	60.8
	CK-C-M-A	Control/Manipulated/Ambient	353.137	2434.79	24.030	165.68	52.9
	CK-C-M-H	Control/Manipulated/High	310.871	2143.38	20.785	143.31	84.9
	CK-E-P-A	Exposed/Pristine/Ambient	688.735	4748.66	24.864	171.43	
	CK-E-M-A	Exposed/Manipulated/Ambient	558.882	3853.35	24.370	168.03	22.0
Upilex	U-C-P-L	Control/Pristine/Low	1193.372	8228.00	59.943	413.29	17.1
	U-C-P-A	Control/Pristine/Ambient	1157.956	7983.82	50.805	350.29	24.9
	U-C-P-H	Control/Pristine/High	772.502	5326.21	45.202	311.66	36.7
	U-C-M-A	Control/Manipulated/Ambient	1093.821	7541.62	50.852	350.61	23.2
	U-C-M-H	Control/Manipulated/High	794.495	5477.85	40.777	281.15	30.4
	U-E-P-A	Exposed/Pristine/Ambient	1257.274	8668.59	44.623	307.66	14.5
	U-E-M-A	Exposed/Manipulated/Ambient	1346.113	9281.11	43.173	297.67	10.8
CP1	CP-C-P-L	Control/Pristine/Low	713.024	4916.12	16.959	116.93	4.0
	CP-C-P-A	Control/Pristine/Ambient	432.842	2984.34	13.492	93.02	7.6
	CP-C-P-H	Control/Pristine/High	336.663	2321.21	9.230	63.64	11.4
	CP-C-M-A	Control/Manipulated/Ambient	452.543	3120.17	13.001	89.64	5.3
	CP-C-M-H	Control/Manipulated/High	304.903	2102.23	7.735	53.33	4.4
	CP-E-P-A	Exposed/Pristine/Ambient	Specimen did not survive irradiation aging process				
	CP-E-M-A	Exposed/Manipulated/Ambient	454.372	3132.78	6.679	46.05	1.6

Figure 6 – Average Tear Resistance Comparison Chart



Based on the test results, the following trends were observed:

(1) Almost all of the materials tested suffered some reduction in tear strength at extreme temperatures when compared to their tear strength at laboratory ambient condition. Kapton HN, tested in the machine direction at −184°C, exhibited the only exception. It has an average increase of 2% in tear strength as temperature drops from 22°C to −184°C. Table 3 summarizes the general tear characteristics by averaging the tear results without considering material direction. Notice that at the maximum operating temperature of 127°C, Kapton E suffered more than 80% drop in tear strength. Also, at the minimum operating temperature of -184°C, Kapton HN maintained tear strength very well in comparison to ambient condition.

(2) On average, at ambient condition of 22°C and 50% relative humidity, Kapton E exhibited the best tear resistance characteristics, follow by coated Kapton HN, Kapton HN, Upilex, and finally CP1.

(3) Upilex, particularly in the machine direction, exhibited the best tear resistance performance at the maximum operating temperature.

(4) Kapton HN exhibited the best tear resistance performance at the minimum operating temperature.

Table 3 – Tear Resistance Summary

Material Samples	Average Tear Strength (N) at 22° C	Average Tear Strength (N) at 127° C	*% Reduction in Strength from Ambient Condition*	Average Tear Strength (N) at - 184° C	***% Reduction in Strength from Ambient Condition***
Kapton E	9.648	1.861	*80.71*	3.76	***61.08***
Kapton HN	4.451	2.263	*49.16*	4.31	***3.07***
Coated Kapton HN	5.453	1.926	*64.69*	4.78	***12.36***
Upilex	3.125	2.277	*27.14*	2.17	***30.70***
CP1	2.502	1.389	*44.50*	1.25	***50.15***

Hourglass Flex Test

The hourglass flex test performed in this effort is based on proven test methods developed and utilized by ILC Dover, Inc. on several other programs where flexing is critical to the item's end-use. The objective of the hourglass flex test is to establish a relative ranking of candidate thin film materials on their resistance to degradation due to flexing. This test does not represent the actual use of the candidate materials, but it offers good insight, by relative comparison under similar testing constraints and conditions, into the materials' resistance to degradation due to flexing in a relative manor (see Figure 7).

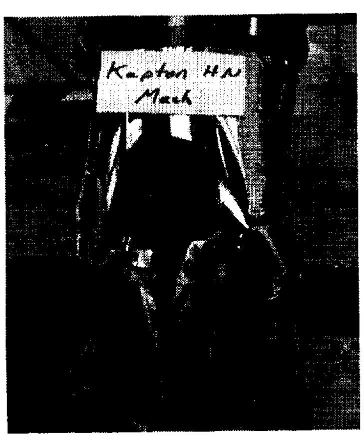
Two distinct data sets were gathered in this test. First, the number of cycles to material failure (i.e. evidence of pinhole or tear) was recorded to determine the thin film material's resistance to flexing. Second, coating degradation was noted while the specimen was being cycled to determine the resistance to the degradation of coating from flexing. The results of the hourglass flex test pertaining to the failure of the thin film materials are summarized in Table 4. The results pertaining to the degradation of the coating are summarized in Figure 8. Based on the results presented in Table 4 and Figure 8, the following trends were observed:

(1) Kapton HN exhibited the best degradation resistance to flexing and the highest resilience to coating degradation based on the average of three specimens.

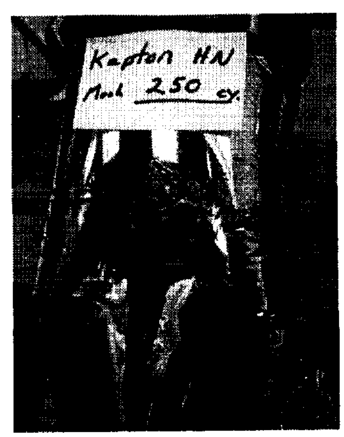
(2) The silver aluminum oxide coating process apparently significantly reduced Kapton HN's ability to resist pinhole failure caused by flexing. Further investigation should be made into the process of coating, particularly the temperature experienced by the film sample, during the coating process. Furthermore, the Ag/Al_2O_3 coated Kapton HN exhibited the fastest coating degradation. (It is also possible that the coating process itself affects the film, regardless of temperature.)

(3) Both Upilex and CP1 performed poorly in the flex test.

(4) Higher modulus material such as Kapton E and Upilex had shown clear evidence of hairline stress fracture prior to coating delamination. The design implication is that the match between coating material and the base film material should be carefully considered in the design process.



Initial condition of the hourglass sample before the flex test



After 250 cycles, no pinholes were discovered. However, some additional coating degradation could be observed, particularly in the widening of flake-off areas. Finally, one pinhole was discovered after 300 cycles.

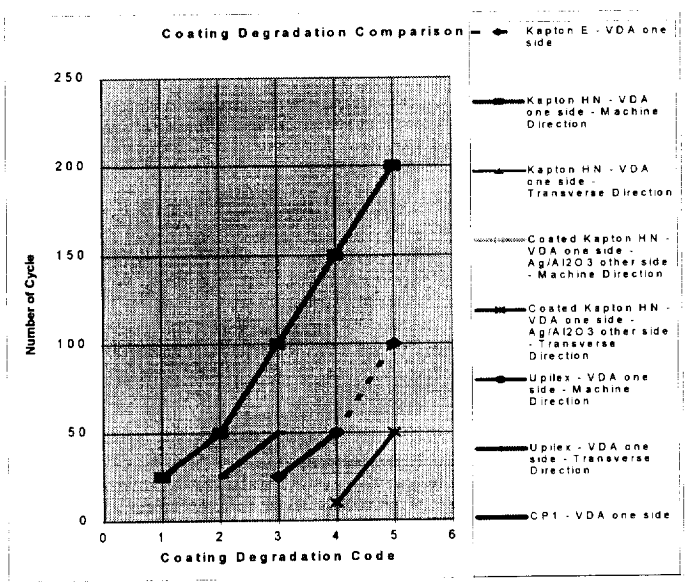
Figure 7 Hourglass Flex Test of Kapton HN

Table 4 – Material Failure Result Summary of the Hourglass Flex Test

Note: One Coated Kapton (Marked X) specimen was not tested to pinhole failure

Film Material Identification	Number of Cycles to Material failure (evidence of pinhole or tear) Specimen Number 01	02	03	Average	Avedev
Kapton E - VDA one side	180	200	174	185	10
Kapton HN - VDA one side - Machine Direction	500	300	350	383	78
Kapton HN - VDA one side - Transverse Direction	400	400	450	417	22
Coated Kapton HN - VDA one side - Ag/Al_2O_3 other side - Machine Direction	100	100	150	117	22
Coated Kapton HN - VDA one side - Ag/Al_2O_3 other side - Transverse Direction	150	50	X	100	50
Upilex - VDA one side - Machine Direction	26	50	16	31	13
Upilex - VDA one side - Transverse Direction		50	90	70	20
CP1 - VDA one side	50	100	50	67	22

Figure 7 – Coating Degradation Comparison Chart



Thermal Radiative Properties

To repeat, the purpose of the NGST sunshield is to block solar energy while passively cooling the telescope for operation at cryogenic temperatures. Therefore, the membrane material used for the NGST sunshield must be able to maintain thermal integrity while surviving ground handling, storage, deployment and the space environmental effects. To obtain a better understanding of how handling and storage may impact the thermal performance of the membrane material, the thermal radiative properties of the five candidate films were measured prior to and after testing by ILC Dover, Inc.

The AZ Technology's LPSR-300 instrument is used to perform the reflectance measurements and solar absorptance calculations following ASTM E903-82 standard test method. The LPSR-300 measures the reflectance of the sample's surface over the spectral range of 250 to 2800 nm at a 15° angle of incidence.

The Gier-Dünkle DB-100 InfraRed Reflectometer is used to measure the normal emittance of the samples following the ASTM E408-71 standard test method. The Gier-Dünkle DB-100 measures the normal emittance of the surface from 5 to 40 microns. This measurement is made at room temperature.
Tables 5 and 6 contain the pre- and post-testing measured thermal properties of the candidate films for each ILC Dover test. The emittance values represented in the tables have been mathematically converted to hemispherical emittance in order to calculate the ratio of absorptance to emittance. The tensile and tear resistance tests are destructive tests; therefore post-testing sample measurements were not possible. The values shown in the table are average values measured. At least five samples of each film were tested. Each film sample was measured in nine different locations across the surface of the film. The samples were measured through the uncoated film side, except for the coated Kapton-HN samples. The Ag/Al_2O_3 coating was measured on the coated (sun-facing) side of the Kapton HN.

The thermal radiative properties show no significant change in pre- and post-test measurements. Due to the flaking of the VDA and Ag/Al_2O_3 coating that occurred during the pinholing test, these results may not give a complete interpretation of the impact of handling and storing on the film's thermal radiative properties. If a significant amount of coating flakes off of the film, the thermal properties will be more representative of the film and not the coating-film combination. Finally, only the coated Kapton HN meets the EOL α/ε requirement of <0.4.

Table 5 Pre-ILC Dover Testing Thermal Radiative Properties Measurements

	Kapton-E			Kapton-HN			Coated Kapton-HN			UPILEX			CP-1		
ILC Dover Test	α	ε	α/ε	α	ε	α/ε	α	ε	α/ε	α	ε	α/ε	α	ε	α/ε
Control	.33	.65	**.51**	.35	.63	**.54**	.08	.49	**.16**	.45	.63	**.71**	.24	.60	**.40**
Handling	.33	.65	**.51**	.35	.63	**.54**	.08	.48	**.17**	.45	.63	**.71**	.23	.59	**.39**
Tensile Testing	.33	.65	**.51**	.35	.64	**.53**	.08	.46	**.17**	.46	.64	**.72**	.25	.61	**.41**
Tear Resistance	.33	.65	**.51**	.35	.64	**.53**	.08	.44	**.18**	.45	.63	**.71**	.25	.62	**.40**
Hourglass Flex	.33	.65	**.51**	.35	.64	**.53**	.09	.49	**.18**	.45	.64	**.70**	.26	.61	**.43**

Table 6 Post-ILC Dover Testing Thermal Radiative Properties Measurements

	Kapton-E			Kapton-HN			Coated Kapton-HN			UPILEX			CP-1		
ILC Dover Test	α	ε	α/ε	α	ε	α/ε	α	ε	α/ε	α	ε	α/ε	α	ε	α/ε
Control	.33	.65	**.51**	.35	.64	**.53**	.08	.52	**.15**	.46	.64	**.72**	.23	.59	**.39**
Handling	.33	.65	**.51**	.35	.64	**.53**	.08	.48	**.17**	.46	.63	**.73**	.23	.59	**.39**
Hourglass Flex	.34	.65	**.52**	.35	.65	**.54**	.09	.51	**.18**	.46	.64	**.72**	.25	.61	**.41**

Properties after Exposure to L2 Environment

Two "manipulated" specimens and one "pristine" specimen of each material was exposed to a simulated L2 environment using Boeing's Combined Radiation Effects Test Chamber (CRETC). Unexposed specimens of both manipulated and pristine material were also evaluated for comparison. The solar absorptance of the 15 exposed samples was measured *in situ* during the L2 simulation. The solar absorptance, thermal emittance, and the tensile properties of the exposed and unexposed specimens were measured following the completion of the L2 simulation.

Simulated L2 Environment

Beams of protons, electrons, and a simulated Sun are available from sources within CRETC. The UV source is a xenon arc discharge, which provides a continuum of photons across the solar ultraviolet wavelengths (200-400 nm). Specific energies of the charged particle beams were 40 keV for the electrons and for the protons. The irradiation rates for the charged particles were accelerated to provide a simulation of a 10-year mission near L2 during a laboratory test period of approximately 700 hours. With the UV source at approximately a 2-Sun rate, 1650 equivalent sun hours (ESH) of UV irradiated the specimens simultaneously with the charged particles. The specimens were exposed to a total electron fluence of 1.6×10^{16} e/cm^2 and a total proton fluence of 2.0×10^{15} p/cm^2. All 15 specimens were exposed during the same run and received all three radiation beams concurrently.

Results

The coated Kapton HN is the only material that meets the solar absorptance over IR emittance (α/ε) ratio requirement (< 0.4) prior to manipulation, even though CP-1 is close to meeting this requirement. The coated Kapton HN still meets the α/ε ratio requirement after manipulation and radiation exposure. The increase in α/ε after manipulation of the coated Kapton HN is due to a decrease in emittance. The increase in α/ε after radiation exposure of the coated Kapton HN is due to an increase in absorptance. Manipulation of the other materials had little or no effect on their α/ε ratio. Radiation exposure did increase the α/ε ratio for the other materials, due to an increase in absorptance. CP-1 had the greatest increase, Upilex-S had the smallest increase, and Kapton HN had to lowest final ratio of the uncoated materials.

Kapton HN had the least amount of decrease in mechanical properties (failure stress/strain). Most of the degradation in mechanical properties occurred as a result of radiation exposure for all materials.

Table 7. Absorptance/emittance (α/ε) ratio vs. test conditions.

Material	Pristine	Manipulated	Manipulated/Radiated	delta α/ε
CP-1	0.42	0.42	0.76	0.34
Kapton E	0.50	0.51	0.68	0.18
Kapton HN	0.54	0.54	0.64	0.10
Coated Kapton HN	0.18	0.22	0.25	0.07
Upilex-S	0.66	0.65	0.73	0.07

Table 8. Failure stress (in ksi) vs test conditions.

Material	Pristine	Manipulated	Manipulated/Radiated	% decrease
CP-1	13.1	13.5	6.7	49
Kapton E	41.6	40.5	30.9	26
Kapton HN	27.6	29.4	26.0	6
Coated Kapton HN 2	9.9	33.2	24.4	19
Upilex-S	50.7	52.5	43.2	15

Table 9. Percent failure strain vs test conditions.

Material	Pristine	Manipulated	Manipulated/Radiated	% decrease
CP-1	7.1	6.6	1.6	78
Kapton E	44.9	33.4	10.3	77
Kapton HN	45.4	56.2	28.1	38
Coated Kapton HN	55.9	71.1	22.0	61
Upilex-S	22.8	25.7	10.8	53

Conclusions

The testing in this effort confirms and extends the conclusions from previous efforts: Kapton E, Kapton HN and Upilex are the strongest candidates. They performed well in handling tests and in the radiation environment. For applications with tight thermal requirements, like the NGST sunshield, these films would require a thermal control coating on the sun-facing layer. The coated Kapton HN maintains its thermal properties and much of its strength after handling and irradiation; however, the coating process significantly reduces the strength of the film. This confirms that the coating process can affect mechanical properties of these films, and the coated material must be tested. CP1 has the best thermal properties without a coating, but it is not strong enough or durable enough for use on the NGST sunshield.

The next phase of this investigation includes:
1) Testing of seaming and rip stop techniques, and
2) Tensile testing at elevated temperatures for films that have been handled and irradiated.

The results with coated Kapton HN underscore the importance of the long term goals for this investigation. After successful seaming and rip stop techniques have been identified for a few of these films, the impact that coating the film has on its mechanical and environmental durability must be evaluated.

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